Insight into the Methodology and Logic Behind

National Marine Fisheries Service

Fish Stock Assessments

Or

How Did You Guys Come Up With Those Numbers, Anyway?

Commonwealth of Massachusetts
Edward J. King, Governor

Executive Office of Environmental Affairs
John A. Bewick, Secretary

Insight into the Methodology and Logic Behind National Marine Fisheries Service Fish Stock Assessments

Or

How Did You Guys Come Up With Those Numbers, Anyway?

Written by:
David E. Pierce
Senior Marine Fisheries Biologist
Massachusetts Division of Marine Fisheries
100 Cambridge Street
Boston, MA 02202
DMF: (617) 727-3193

Patricia E. Hughes
Marine Fisheries Biologist
Massachusetts Coastal Zone Management Office
100 Cambridge Street
Boston, MA 02202
CZM: (617) 727-9530

The printing of this publication was funded by the Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, U.S. Department of Commerce under a program implementation grant to the Commonwealth of Massachusetts.

THE COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE DEPARTMENT
STATE HOUSE • BOSTON 02133

EDWARD J. KING
GOVERNOR

January 25, 1979

Dear Reader,

I am pleased to present the members of the public this paper which describes the way in which fisheries scientists estimate the health and size of the fish stocks in the waters off New England. This biological information is used by the New England Fisheries Management Council in developing fisheries management plans. Some fishermen and others have expressed concern about the way the 200 mile fisheries conservation law has been implemented. This publication seeks to answer some of these questions. It was developed jointly by staff in the Division of Marine Fisheries and the state's Coastal Zone Management Office, both within the Executive Office of Environmental Affairs headed by Secretary John A. Bewick.

Commercial fishing is one of the Commonwealth's oldest industries and today contributes some one-half billion dollars annually to our economy. This administration looks forward to an expanded and more productive commercial fishing industry in the years to come.

Sincerely,

Edward J. King

EDWARD J. KING
Governor

INTRODUCTION

The National Marine Fisheries Service provides the various Regional Fishery Management Councils with stock assessments that are used to help determine that portion of the fish stock which may be harvested (optimum yield), given certain management objectives. In order for management to be effective, these assessments must be acceptable to those being regulated; otherwise, management measures implemented by the Councils are doomed to failure.

Unfortunately, during 1977 many New England fishermen felt that some groundfish assessments made by the Northeast Fisheries Center (NMFS) appeared to contradict their observations made during actual fishing operations. As a result, optimum yields, which at that time were based by the New England Council primarily on scientists' estimates of catches required to maintain or increase stock sizes in later years, met with a great deal of skepticism. Fishermen commonly asked "How did you guys come up with those numbers anyway?" Questions such as this and criticisms resulted, in part from a lack of understanding of what information scientists used to perform their assessments and how it was gathered, what assessments' results actually indicated, and what the role of assessments was in the setting of optimum yields by the New England Council.

Since the need for assessments and the Councils' dependencies on them are here to stay, it is extremely important that all concerned individuals become familiar with the assessment process, else the same questions and confusion will arise year after year. For example, as part of a fish stock assessment, the following basic information is needed: past and present age composition of the stock; number of young fish which eventually enter a fishery (recruitment); weight of the stock; growth rates; deaths due to fishing; and deaths due to factors other than fishing. This information is collected from two main sources: NMFS bottom trawl surveys and fishermen in the form of commercial and recreational catches and/or landings.

Our intent is for this paper to be readable and understandable by fishermen, administrators and Council members. However, we don't pretend to believe that everything will be made clear and all questions laid to rest. Some sections must be read carefully and deliberately. We feel the scientific language has been kept at a minimum and that frequent, specific examples, particularly in the stock assessment section (appendix), which is very difficult to make understandable to laymen, illustrate certain important points.

The material presented attempts to guide the reader through the methodology and logic behind the surveys and to relate the information obtained from commercial and recreational catches and landings. A simplified example is given to illustrate how all this information is used to produce a fish stock assessment; more detailed information is given in the appendix. A list of definitions of important, commonly heard, scientific terms is also presented (italicized terms in the text are defined in the glossary).

If nothing else, we hope that one point is made clear. Scientists use commercial and recreational catches and landings (when available and reliable) to perform fish stock assessments. Accurate information gathered from commercial and recreational catches and landings, whether it be from logbooks, dealer weighout slips, etc., is at least as important as the results from the bottom trawl surveys. They complement one another. Quantities, locations, and age-length data of catches (not just landings) and records of fishing effort (number and duration of tows) are indispensable for accurate assessments which give a true reflection of the status of the stocks.

We welcome all questions. If we have failed to cover specific points of interest or if further explanations of material covered are needed, please let us know by calling either 617-727-3193 (DMF) or 617-727-9530 (CZM), or by writing to either one of us at the addresses shown on the title page.

RESEARCH VESSEL BOTTOM TRAWL SURVEY

Purposes

1) To obtain annual estimates of the *relative abundance* of major finfish species in terms of both number and weight (*biomass*).

2) To determine long term changes or trends in relative abundance and species composition of the entire groundfish community, not just a few species such as cod, haddock and yellowtail flounder.

3) To describe fish distribution on a very broad scale in relation to bottom features, geography and environmental factors such as temperature.

4) To gather information on age and species composition, growth and maturity changes, mortality, food habits, *stock* identification, future *recruitment* and other biological as well as environmental data.

Survey Areas

1) Historically, surveys have ranged from 15-200 fathoms from Cape Hatteras to Nova Scotia (75,000 square nautical miles). Currently, surveys extend from approximately 4-200 fathoms and reach southward to Cape Fear, North Carolina.

2) There are five depth zones (in fathoms): approximately 4-14 (referred to as the inshore zone); 15-30; 31-60; 61-100; greater than 100. Each zone is divided into separate sampling areas which are called strata. From Cape Hatteras to Nova Scotia (15-200 fathoms) 65 strata have been established based primarily on geography (latitude) and depths. These strata may be combined to represent the Middle Atlantic, southern New England, Georges Bank, and Gulf of Maine regions (Figure 1). The inshore zone from Cape Hatteras to Nova Scotia is divided into 74 strata; an additional 15 strata extend southward to Cape Fear. These strata have also been established based on geography and depths; the locations of major estuaries (for example, Chesapeake Bay) and coastal configurations have influenced the number and size of each stratum.

3) Until recently, inshore tows (less than 15 fathoms) were made occasionally. Now, inshore tows are regular features of the surveys, especially those performed in the Mid-Atlantic. Inshore tows are stressed in recently begun summer surveys since fish tend to move inshore during the warmer summer months, particularly in the Mid-Atlantic region. The number of inshore tows during the summer in the more northern regions, for example, the Gulf of Maine, is more limited due to the nature of the bottom and great abundance of fixed gear.

Stations (Tow Locations)

1) Time considerations limit the number of stations (tow locations) per season to 250-300. A predetermined number of stations within each stratum is selected at random before each cruise. The procedure for determining the numbers and locations of tows per stratum is essentially as follows:

For the offshore zones (15-200 fathoms):

a) The number of tows in a given stratum is predetermined and roughly proportional to the area of each stratum. In other words, the larger the stratum, the greater the number of tows.

b) The smallest number of stations in a stratum is two; this is typical of narrow strata along the shelf edge in the Mid-Atlantic.

c) Each of the 65 strata (15-200 fathoms) is subdivided into rectangles of standard size (5 minutes latitude by 10 minutes longitude).

d) Each rectangle is further subdivided into 10 smaller rectangles (2½ minutes latitude by 2 minutes longitude). Every stratum, therefore, is subdivided into a large number of 2½ by 2 minutes rectangles which are then numbered consecutively starting with 001.

e) For each stratum, numbers are randomly chosen (from a table of random numbers — statistically accepted practice) until the predetermined number of stations is obtained. Tow locations correspond to the numbered 2½ by 2 minutes rectangles selected. A constraint is that only one tow can be selected for each 5 by 10 minutes rectangle in a stratum. This ensures that all possible tow locations in a given area have an equal chance of being chosen during any one cruise (randomization).

f) An entire stratum often cannot be subdivided into equal 5 by 10 minutes rectangles due to the irregular boundary of that stratum. Therefore, in this case, irregular shaped blocks are formed with the area of each block equalling that of a 5 by 10 minutes rectangle.

For the inshore zone (less than 15 fathoms):

a) Each strata is divided into 2½ minutes latitude by 2 minutes longitude rectangles. Since the inshore strata are smaller than those offshore, there is no initial subdivision to 5 by 10 minutes rectangles.

b) Each 2½ by 2 minutes rectangle per strata is numbered. For each stratum, numbers are randomly chosen until a predetermined amount per stratum is obtained. The only constraint is that no adjacent rectangles may be selected.

After tow locations are selected, a cruise route is established; the route ignores stratum boundaries and attempts to minimize steaming time. Extra stations are added in the route to fill gaps in large areas which lack stations selected by the above methods (no more than 6 are added per survey).

During the survey, tow locations may be moved or omitted if the original location is found to be near a charted obstruction or the haul leads to net damage. Alternate tows are made nearby in the same stratum and depth. Every effort is made to tow on original locations.

2) Average sampling intensity from Cape Hatteras northward (15-200 fathoms) represents roughly one trawl haul every 300 square miles (includes non-trawlable areas).

3) It is not always possible to finish an entire survey because of weather, vessel breakdowns, etc.; however, key regions (southern New England, Georges Bank, and the Gulf of Maine) receive top priority and are always covered on each survey.

In 1977, during the autumn bottom trawl survey (September 26 - December 5), 100 tows were made on Georges Bank-South Channel; 64 tows in the Gulf of Maine; 63 tows in the southern New England region (27 additional tows inside 15 fathoms); and 59 tows in the Mid-Atlantic region (48 additional tows inside 15 fathoms) (Figure 2).

Time of Surveys

1) Autumn (since 1963); spring (since 1968); summer (since 1977).

2) Approximately 10 weeks to cover Cape Hatteras to Nova Scotia during each survey.

3) 24 hours a day during each survey.

In 1977, surveys were performed from March 19 - May 14, July 27 - August 13, and September 26 - December 5.

Vessels and Gear

1) Research vessels Albatross IV (187 foot stern trawler; in use since 1963) and the Delaware II (155 foot stern trawler; infrequent in past years but recently being used more often) are of equal *fishing power.* Foreign vessels are also used in joint, cooperative surveys, but these survey data are only used to supplement U.S. survey results.

2) Fall and summer surveys use the #36 Yankee trawl while the spring surveys use the high opening, 2 seam #41 Yankee trawl (since 1973).

3) #36 Yankee and #41 Yankee trawls are 5 inch mesh throughout except for a 4½ inch mesh cod end with a 1/2 inch mesh liner in the cod end and upper belly; both are fished with rollers, thus tows on rough bottom are possible.

	#36	#41
Effective headrope height	10-12'	14-16'
Effective wingspreads	32-36'	34-37'
Footrope	80'	100'
Legs	5 fathom	10 fathom
Doors	1,200 lbs. BMV oval	1,500 lbs. BMV oval

4) 16 inch diameter, 5 inch wide, hard rubber rollers with 6-7 inch long, 1/2 inch diameter rubber spacers along the footrope.

5) 36 floats of 8 inch diameter; aluminum, deep sea type.

Tows

1) Thirty minute tows are made at each station at an average speed of 3.5 knots. The speed through the water has previously been indicated by an electromagnetic log; however, a Doppler Speed Log is now in use. A Doppler provides an immediate record of vessel velocity and a cumulative readout of distance traveled over the bottom.

2) Tows are made with enough wire to obtain a scope of 3:1 except in water greater than 150 fathoms where a 2½ :1 scope is used.

3) Tow direction is on heading toward the next station on the route except when wind and sea states are unfavorable. Tows are made along depth contours to maintain constant depth.

Limitations

1) The exact number and weight of each species in a given area (absolute abundance) is impossible to determine. The sampling reflects increases or decreases in the relative abundance of fish stocks and is therefore a useful measure of change in absolute abundance.

2) With a series of annual surveys, scientists can test for significant trends in relative abundance with time; that is, whether there is a decline or an increase in relative abundance over a period of years. Because fish are not uniformly distributed, a great many tows are required to detect small yearly changes in stock size, in some regions as many as 350-500 tows. This sample size is not possible due to time, vessel and personnel limitations. Current *abundance indices* (*stratified mean catches per tow*) are only *precise* enough to detect major changes in stock size between years. Generally, it takes several years before major changes in stock size occur.

Management policy has a great deal of influence on whether or not the lack of high precision is a limitation. If managers decide that it is only necessary to detect when large changes (for example, 50% and greater) in relative abundance have occurred, then the survey's lack of high precision is not a limitation. However, if the detection of small yearly changes (for example, 5-10%) in relative abundance is required, the lack of high precision presents a problem.

3) While a number of inshore areas (less than 15 fathoms) from Cape Cod to Cape Hatteras have been sampled during the spring and fall bottom trawl surveys (since 1972) and more so during the summer surveys, the coverage of inshore areas, particularly in the New England region, is less intensive than that of offshore areas (greater than 15 fathoms). In addition, rocky bottoms (for example, rock piles) are not surveyed due to the likelihood of hang ups and "rimracks." Consequently, measures of relative abundance and distribution of some inshore species and young-of-the-year of some inshore and offshore species may not be truly representative.

To increase the coverage of the New England inshore areas, the State of Massachusetts Division of Marine Fisheries has begun spring and fall bottom trawl surveys with a contracted commercial fishing vessel. This involves approximately 90-100 20 minute tows per survey within Massachusetts territorial waters from the New Hampshire to Rhode Island borders. Spring and fall 1978 surveys have been completed. The State of Maine Department of Marine Resources also intends to perform similar survey work off its shores; none has been completed as yet.

4) Tow locations are randomly selected and are therefore widespread. The survey design is limited when there is a need to assess the relative abundance of a particular species and that species' seasonal movements are local and primarily restricted to specific areas. However, unchanged habits and distributions between seasons in different years are exceptional rather than common.

It should be noted that recently the Northeast Fisheries Center has begun to ask for fishermen's suggestions as to where additional survey effort should be placed. The Center has modified and intends to continue to modify its surveys' patterns of tows to comply with some of the suggestions.

Reasons for the Need of Bottom Trawl Surveys

1) Since commercial fishing strategies vary according to market conditions and prices, commercial landings reflect only those species and sizes suitable or desirable for market in a given port at a particular season. In contrast, entire catches (all species and sizes) of research vessels' hauls are examined and recorded.

2) Since commercial vessels generally fish where catches are expected to be greatest, fishing patterns vary according to fish availability which may be related more to fish aggregation than relative abundance. If in different years stock abundance remains the same but fish distribution changes in response to some factor (perhaps temperature) so that fish become more aggregated or concentrated, commercial catch results will suggest false increases in relative abundance, and vice versa. This same reason applies for not performing research vessel surveys only in areas where catches are expected to be greatest. However, if habits and distribution of a fish stock do remain unchanged between years, commercial catches alone may give satisfactory estimates of changes in relative abundance of the stock with time. This is possible provided gear efficiency does not change with time and the Northeast Center is provided with accurate catch and effort records by area and is able to perform sufficient port sampling.

3) Over the years, fishing power of commercial vessels has changed due to technological improvements, etc., while the research vessels' fishing powers have not varied. Consistent use of particular trawl nets and 30 minute hauls has resulted in a standardized fishing method.

4) Small mesh liners enable retention of young-of-the-year and juvenile fish of many species. This enables estimates of the number of fish which will enter a fishery in future years (*year-class* strengths and recruitment).

5) Fish distribution and seasonal movements as influenced by the environment can be investigated.

6) Estimates of abundance of "non-traditional" species are possible.

7) Regulations (for example, catch limitations) encourage or make necessary high discard rates, false reporting, and even smuggling; therefore, reliable estimates of total removals from the stock by area, and records of commercial landings and effort become difficult to obtain. Greater reliance on bottom trawl survey results becomes necessary.

COMMERCIAL STATISTICS

Personnel

1) 18 Offices: MAINE — Eastport, Rockland, Portland; MASSACHUSETTS — Gloucester, Boston, Plymouth (covers Harwich to Westport), Provincetown (covers Chatham), Woods Hole, New Bedford; RHODE ISLAND — Newport (covers Connecticut), Point Judith; NEW YORK — Greenport, Patchoque; NEW JERSEY — Cape May, Tom's River; MARYLAND — Easton; VIRGINIA — Franklin City, Hampton.

2) Staff: Total of 31 permanent employees (17 port samplers and 14 supervisory and administrative personnel); New England has 10 port samplers and 6 supervisory and administrative personnel (Newport has one person with both responsibilities), plus 5 co-op students who work in the port sampling section.

Sources of Information

1) Dealer weighout slips: provide information on pounds and ex-vessel prices of fish species landed; catches are generally recorded by vessel and on a trip basis.

2) Vessel captain interviews: provide information on pounds of fish caught ("hail") by species, area fished and gear type, time, number and duration of tows or sets, and estimates of catch of each species discarded.

3) Logbooks: provide information similar to that obtained from vessel captain interviews. Weights of catch by species are estimates.

4) Commercial catch samples: dockside sampling to determine length and age compositions of the landings, growth rates, and length/weight relationships of different species.

5) Sea sampling: on board collection of information on length and age composition of catch and amount of discards by species.

Coverage

1) Weighout slips: 95% of New England landings are assumed by NMFS to be reflected in the monthly collections from dealers; weighout information is collected in Maine, Massachusetts, Rhode Island, and New Jersey. Landings in the other states (New Hampshire, Connecticut, and in the Mid-Atlantic) are collected monthly (total landings by species, no breakdown by vessel or trips), but will be incorporated into the system in the near future.

2) Interviews: 50-60% coverage of greater than one day vessel trips; 10-15% coverage of day trip vessels. Percent coverage of total weight landed is greater than coverage for individual trips.

In 1977, 3,500 greater than one day vessel trips were interviewed out of a total of 7,000 trips made. Out of 41,000 day trips made, 6,150 trips were interviewed.

3) Logbooks: currently required for headboats and groundfish vessels greater than 100 gross registered tons (GRT); logbooks will soon be mandatory for all groundfish vessels.

4) Commercial catch samples: daily sampling by area; for a given species catches from a selected combination of sub-areas of statistical areas are sampled — see Figure 3. Catch samples are obtained throughout the year for 29 species; two illustrations are:

Yellowtail flounder — since this species is landed and sorted by count (number per 125 pound box), each different count is sampled for length and age; attempts are made to obtain one length *sample* (100) fish) and age sample (50 fish) per count, sampling area, and quarter of the year.

Cod and haddock — attempts are made to obtain 5 length samples (50-100 fish each) and 5 age samples (15-20 fish each) per market category, month and sampling area.

There are also sampling requirements by regional area and by port.

Problems

1) Weighout slips are not collected in every port due to a lack of personnel.

2) In some instances, consignment shipping of catch makes impossible a record of first landing location.

3) Extent of discard is difficult to evaluate since fishermen are asked to estimate the amount of discard by species, and are often reluctant or unable to provide the information.

4) Gaps in coverage exist even for species of major commercial importance due to a lack of funds and personnel and an insufficient amount of port sampling by area, gear type, etc.

5) Participation and cooperation in the logbook program is not complete, and the accuracy of the information is questionable. The greater the accuracy of

logbooks, as well as weighout slips, etc., the greater the ability of the NMFS assessments to depict the true nature and status of different fisheries and fish stocks.

6) Some transactions are never recorded; for example, purchases by restaurants.

7) Extent of coverage in sea sampling program is limited due to personnel, funding and some insurance coverage problems.

8) False reporting occurs to "get around" regulations. For example, reporting yellowtail from W69 when caught in E69 waters; reporting one species as another (cod as pollock); reporting catch from inside territorial waters when actually taken outside in the Fishery Conservation Zone (FCZ).

RECREATIONAL STATISTICS

In 1960, 1965, and 1970, door to door household interviews were conducted during the National Survey on Fishing and Hunting. Information was provided, on a regional basis, on number of anglers and number and weight by species of fish caught. In 1974, NMFS conducted a Northeast region telephone survey which collected the same information as the previous surveys. Since 1974, a number of smaller surveys, principally in the mid-Atlantic region, have been done to collect information for specific species. In the fall of 1978 an extensive intercept and phone survey of recreational catch was begun.

The weight by species caught is used by Northeast Fisheries Center scientists in their stock assessments.

A SIMPLIFIED EXAMPLE OF ONE METHOD USED TO DETERMINE STOCK ABUNDANCE AND EFFECTS OF DIFFERENT LEVELS OF CATCH

1) Total Catch — Commercial landings (weight) by the U.S., Canada, and other countries are obtained. Recreational catch (angler, charter/headboat) is estimated from Marine Angler Surveys. Discards are estimated from logbook records, fishermen interviews, and fishermen scuttlebutt.

2) Total Length Composition — *Length frequency* information is obtained from commercial and recreational samples and from foreign catches. This information is applied to catch from specific areas to estimate length frequency of total catch from those areas.

3) Total Catch Age Composition — Age/length relationships or "keys" are established from commercial and/or research vessel survey catches. "Keys" are then applied to commercial length frequencies to estimate age composition. The resulting age frequency is then increased by proportionately distributing recreational catches within the frequency.

4) Stock Size in Past Years — With determination of catch age composition over a period of years, and an estimation of *natural mortality* and *fishing mortality* in the most recent year, techniques are available to determine past stock sizes and fishing mortality over time. A Virtual Population Analysis (VPA) is one such method used to determine past stock sizes and fishing mortalities of different year-classes at each age. The total stock weight in metric tons can be obtained by applying commercial weight at age information determined from biological sampling to numbers at age calculated from, for example, the VPA.

5) Current and Future Stock Size — Techniques are available which can be used to evaluate current stock size and to predict future trends in stock size under various assumptions of recruitment and discard. To illustrate how research vessel survey results are used to predict future prospects for fisheries, the following example is given:

It may be possible to set up a relationship to determine the size of a year class which has yet to enter a fishery but is catchable in the research vessel trawl survey if the following holds true: poor catches in the research trawl survey of a series of past year-classes correspond to poor abundance of the same year-classes when they are commercially and recreationally exploited, and high catches in the trawl survey of a series of past year-classes correspond to high abundance when those year-classes enter the fishery. Therefore, if the relationship can be established and a particular survey results in good catches of a year-class, then it is possible to predict that abundance of older ages of that year-class will also be good. Hence prospects for the future of the fishery will be promising.

6) Effects of Future Catch — A group of options of future catch and resultant stock size are calculated and presented to the Fishery Management Councils. The setting of optimum yields or total allowable catches is done by the Councils after consideration of the options with regard to Council objectives.

Other types of assessments exist to determine the status of fish stocks. The type depends on the kinds and amounts of reliable information which is available to the scientist and the objectives of management which are set independently of the scientist. This dicates whether an assessment can be sophisticated or relatively simple and not complex.

APPENDIX

A DETAILED EXAMPLE OF ONE METHOD OF STOCK ASSESSMENT

1) Landings (weight) by the U.S., Canada, and other countries plus estimates of recreational catch (angler, charter/headboat) and discards are obtained. The recreational catch and discards, unlike commercial landings, are difficult to determine (at times, commercial landing data are not always satisfactory for many species); therefore, stock assessments may be performed under different assumptions of total recreational catch and percentage of discards. Marine angler surveys are sources of estimates of recreational catch while percentage of discards are available from logbook records, fishermen interviews, sea sampling and fishermen scuttlebutt.

2) Length frequency information for a particular species is obtained from U.S. commercial and recreational samples and from foreign catches of that species if an allocation exists. This information is applied, depending on the amounts of data available, to monthly, quarterly, half-year, or annual catch from specific areas to estimate length frequency of the total catch from those areas. When possible, length frequency information is applied to catch by harvesting sector (for example, by gill netters, longliners, otter trawlers, etc.). As an illustration, the following procedure might be used:

a) From a number of vessels, samples of a particular species (of each market category if separated) are taken by measuring the lengths of fish in one or more boxes, baskets, etc., per vessel. The weight of each sample can be determined after-the-fact by previously estimated length/weight relationships. In other words, by knowing the number of fish and each of their lengths in the samples, the weights for each fish can be estimated to determine the total weight of the samples.

b) Results of all sampled landings of a species caught from specific areas are added together to give sample length frequency and weight by area for a given time period, such as a month.

c) By knowing the total landings and the areas fished during that period, the length frequency of sampled landings can be expanded to estimate the length frequency of total landings by area for all vessels. The eventual outcome is a length frequency by area for an entire year.

For example, suppose during May a cod length distribution is obtained from samples (approximately 1000 fish) of 10 vessels that fished in South Channel (Statistical area 521 — see Figure 3). It is determined from a length/weight relationship that the total weight of the samples is 5,000 lbs. It is also known from weighout slips, logbooks, interviews, etc., that a total of 200,000 lbs. was landed from the South Channel in May by vessels from various ports. The total weight is 40 times the amount of the sampled weight (200,000 ÷ 5,000); thus the length frequency determined from the samples is multiplied by 40 to obtain an estimate of the length composition of landings in all ports of cod caught in the South Channel during May.

3) Age/length relationships or "keys" are established from commercial samples when enough data are available; otherwise, they are determined from spring and fall bottom trawl surveys. "Keys" are then applied, in some cases by calendar quarter, to commercial length frequencies. This provides an estimate of total commercial landings age composition (by number, not weight). The resulting age frequency is then increased by proportionately distributing recreational catches within the frequency. The following is a representation of how an estimate of age composition (over a selected length range) might be obtained by application of an age/length key to final results of step 2 (total length composition).

Length Category (inches)	Total scale or otolith samples examined per category	Age as determined from scale and/or otolith examination				Total number of fish by length category estimated in step 2 (thousands of fish)	Estimate of total age composition (thousands of fish)			
		2	3	4	5		2	3	4	5
14-16	500	400	80	20	0	1500	1200	240	60	0
17-19	500	65	375	60	0	2600	338	1950	312	0
20-22	500	30	110	250	110	4500	270	990	2250	990
							1808	3180	2622	990

To explain further, from scale and/or otolith (earbone samples taken from 500 fish which ranged from 14-16 inches, 400 are found to be age 2, 80 age 3, 20 age 4, and none age 5. In other words, 80% are age 2 (400/500), 16% age 3, 4% age 4, and 0% age 5. These percentages are applied to the total number of fish in the same size range or category determined in step 2. Thus, if 1,500,000 fish from 14-16 inches comprise the commercial landings, then 1,200,000 are age 2 (0.80 x 1,500,000), etc. The number of fish of each age over all lengths is obtained by addition; for example, from 14-22 inches there are 1,808,000 age 2 fish (1,200,000 + 338,000 + 270,000), etc. The length categories can be varied and are normally recorded in metric units (millimeters or centimeters).

4) A Virtual Population Analysis (VPA) is performed to estimate past stock sizes in numbers of fish and fishing mortalities of different year-classes at each age. For any one calendar year, the sizes of the various year-classes are added to obtain an estimate of total stock size in that year. For example, total stock size of a particular species in 1976 might be estimated by adding the following: age 1 of the 1975 year-class; age 2 of the 1974 year-class; age 3 of the 1973 year-class, etc.

This method requires an estimate of natural mortality (M), total catch (C) of each age of different year-classes estimated from step 3 and an estimate of fishing mortality (F) for the oldest age taken in the fishery. This information is used in the relationships:

$$C = N \frac{F}{F+M}(1-e^{-(F+M)}) \quad (1)$$

$$\frac{N}{C} = \frac{(F+M)(e^{-(F+M)})}{F(1-e^{-(F+M)})} \quad (2)$$

e is a mathematical constant and always equals 2.718

The manner of assessment cannot be given proper treatment without mathematical expressions.

The first relationship is called the catch equation. It simply means that total catch (C) in a year of any age of a particular year-class is equal to the number of fish of that age (N) at the beginning of the year multiplied by the percentage of those fish caught that year. By knowing C, F, and M, N can be calculated. For example, if from step 3 it had been estimated that in 1976, 175,000 age 7 fish (1969 year-class) were caught, fishing mortality in 1976 was 0.55, and natural mortality equalled 0.20, then the number of 7 year old fish alive at the beginning of 1976 would have been 452,000. The ways to calculate F and M are too diverse to discuss in this paper, thus no explanations of how the values are obtained, as well as the logic behind some of the equations, are given in this paper.

$$175{,}000 = N \frac{0.55}{(0.55 + 0.20)}(1-e^{-(0.55 + 0.20)}) \quad (1)$$

$$N = 452{,}000$$

To determine the number of 6 year old fish alive at the beginning of 1975 (again the 1969 year class), the value of fishing mortality of that age during 1975 must first be determined by equation (2). N represents the number of 7 year old fish alive at the beginning of 1976 which was just calculated. C now represents the number of 6 year old fish caught in 1975 (estimated in step 3). If 477,000 6 year old fish were caught in 1975, then equation (2) takes the following form:

$$\frac{452{,}000}{477{,}000} = \frac{(F + 0.20)(e^{-(F + 0.20)})}{F(1-e^{-(F + 0.20)})} \quad (2)$$

$$F = 0.664$$

F is determined by trial and error; a computer is utilized to perform the calculations. F is the only unknown in the above equation and is calculated to be 0.664.

The catch equation is again utilized but with F equal to 0.664 in place of 0.55. Since in 1975, 477,000 6 year old fish were caught, the number of 6 year olds alive at the beginning of 1975 is calculated to be 1,073,000.

$$477{,}000 = N \frac{0.664}{(0.664 + 0.20)}(1-e^{-(0.664 + 0.20)}) \quad (1)$$

$$N = 1{,}073{,}000$$

Equation (2) is again used to calculate the next F value, the catch equation to determine the number of 5 year old fish alive at the beginning of 1974, and so on until the past history of the year class is determined. This procedure is followed for each year-class in the fishery and as stated previously, for any one calendar year, the sizes of the various year-classes are added to obtain an estimate of total stock size in that year.

5) Average weights at the beginning of the year of fish at the various ages are applied to stock size at each age (numbers) calculated from the VPA as in step 4 to obtain stock weights at the beginning of each year. The following gives an illustration of the procedure used to calculate stock size in a particular year (for example, 1976) for a particular species:

Year-Class	Age	Average weight (lbs. per fish)	Number of fish of each age calculated from step 4 (thousands of fish)	Total weight of each age (thousands of lbs.)
1975	1	½	34,000	17,000
1974	2	1½	25,500	38,250
1973	3	3	13,800	41,400
1972	4	5½	7,650	42,075
1971	5	8	3,550	28,400
1970	6	12	1,600	19,200
				186,325 pounds or
				84,539 metric tons

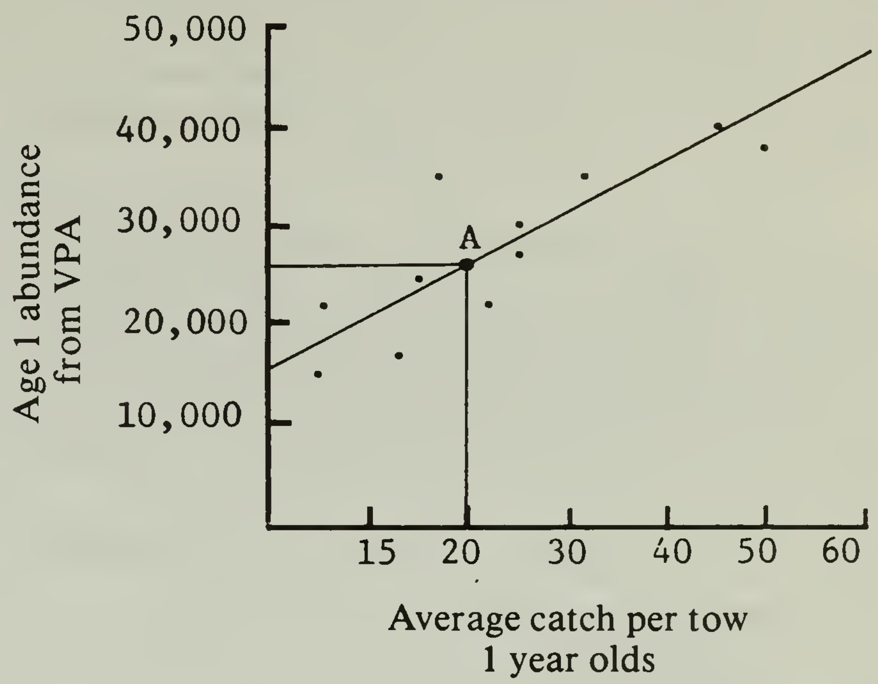
To explain, assume that in 1976 it is estimated from the VPA (step 4) that 34,000,000 one year old fish are present. At an average weight of ½ pound per fish, the total weight of one year old fish is 17,000,000 pounds (34,000,000 x ½). At an average weight of 1½ pounds per fish the total weight of two year old fish is 38,250,000 pounds. This procedure is performed for each age and the results added to estimate the total weight of the stock (84,539 metric tons) in 1976 for ages 1-6.

6) At the completion of step 5, the histories of stock sizes in past years are known. The next step involves an estimate of present stock size, then a projection into the future. The following procedure with the assumption that 1977 is the current year might be used to estimate the above information.

An estimation of abundance of each age group (different year-classes) present in the stock during 1977 must be made. First, a relationship is determined between annual estimates of abundance obtained from the VPA of young ages (for example, ages 1-3, which in this case are considered not yet catchable or are partially catchable by fishing vessels) and past autumn bottom trawl survey average catch per tow of those same ages. The data used to establish this relationship might be as follows:

Year	Age 1 abundance from VPA (thousands of fish)	Average catch per tow 1 year olds
1963	25,765	15.2
1964	17,151	13.4
1965	22,600	6.2
1966	15,000	5.1
1967	22,759	22.3
1968	35,454	18.5
1969	27,000	26.2
1970	30,562	26.4
1971	40,150	45.7
1972	36,572	33.0
1973	39,532	49.9

The data can be illustrated graphically as:



If a line (straight or curved) can be fit statistically through these points, a predictive relationship can be determined. In other words, if an estimate of relative abundance of age 1 fish (average catch per tow) from a bottom trawl survey is obtained, by referring to the graph, an approximate value of the corresponding abundance of one year old fish (numbers) can be determined. If in 1977 the autumn bottom trawl survey resulted in an average catch of 20.0 one year old fish, then an estimate of one year old fish from the graph would have been approximately 27,000 at the beginning of 1977 (point A).

A similar procedure is followed for the rest of the not yet catchable or partially catchable ages to determine their abundance at the beginning of 1977. In this example, the abundance of age groups 2 and 3 must also be calculated.

Once these values are obtained, they are inserted in equation (3) to estimate size of year classes during the coming year.

$$N_1 = N_0 e^{-(F+M)} \qquad (3)$$

This relationship simply means that size of an age group of a particular year-class at the beginning of the current year (N_0) multiplied by percent survival ($e^{-(F+M)}$) equals the size of that year-class at the beginning of next year (N_1). If, for example, the 1977 abundance of one year old fish was 27,000,000 and survival of these fish was determined to be 78% during 1977, then 1978 abundance of these same fish at age 2 would be 21,060,000.

$$N_1 = 27{,}000{,}000 \times 0.78 = 21{,}060{,}000 \qquad (3)$$

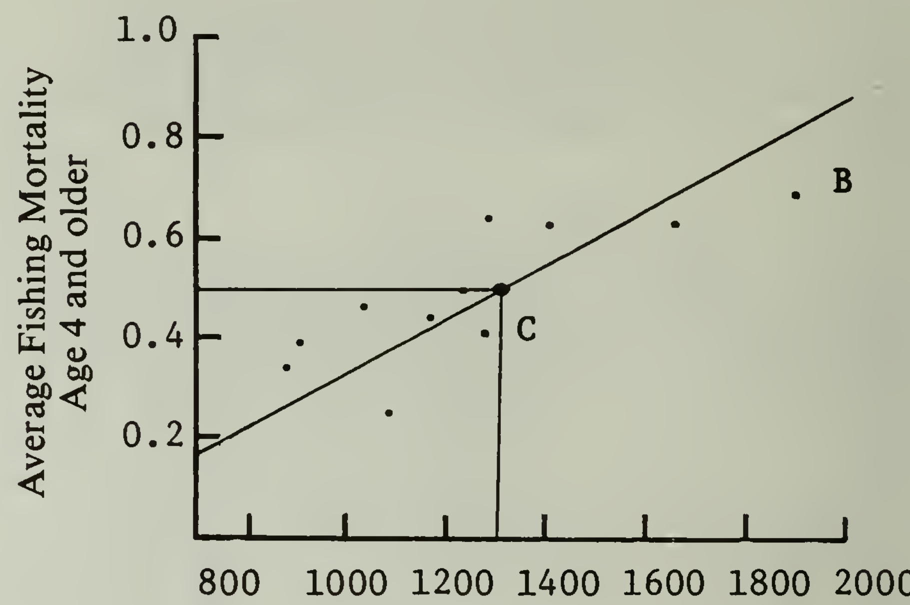
This procedure is followed until 1978 abundance of ages 3 and 4 are calculated. Age 1 abundance in 1978 can be estimated, in some instances, by a relationship between past survey catch per tow of young-of-the-year fish (age 0) and resulting one year old fish a year later (from the VPA).

Secondly, 1977 abundance is calculated for those ages (for example, ages 4 and older) which are fully catchable by fishing vessels. By knowing catch and having an estimate of fishing mortality of age 4 fish in 1977, the abundance of 4 year old fish at the beginning of 1977 can be determined from equation (1) as shown in step 4. Once this abundance is obtained, it is inserted into equation (3) to calculate the number of 5 year-old fish at the beginning of 1978. And to continue, by knowing catch and fishing mortality of age 5 fish in 1977, the abundance of 5 year-old fish at the beginning of 1977 can be determined from equation (1). Once this abundance is obtained, it is inserted into equation (3) to calculate the number of 6 year old fish at the beginning of 1978. This procedure is followed in step-wise fashion until the abundance of the oldest age at the beginning of 1978 is determined.

Values of 1977 fishing mortality of the young, not fully catchable ages (needed to calculate the above) are determined by procedures similar to those in step 4. Fishing mortality in 1977 for the fully catchable ages is obtained in another way, however. Annual fishing effort indices are determined by dividing total catches of fully catchable age groups (age 4 and older) by the autumn survey catch per tow of these same age groups. A relationship is then set up between these effort indices and average values of fishing mortality for the fully catchable ages obtained from the VPA (step 4). The data used to establish this relationship might be as follows:

Year	Autumn average catch per tow	Catch thousands of fish	Fishing Effort Index	Average F
1963	5.5	10,549	1918	0.66
1964	10.1	12,670	1254	0.40
1965	7.6	10,600	1395	0.62
1966	8.0	9,750	1219	0.48
1967	15.7	17,987	1146	0.42
1968	20.0	20,576	1029	0.44
1969	22.5	19,490	866	0.32
1970	30.0	26,757	892	0.38
1971	18.9	19,711	1043	0.24
1972	6.8	11,000	1618	0.62
1973	15.0	18,971	1265	0.62

The data can be illustrated graphically as:



For example, if in 1963 the autumn average catch per tow was 5.5 fish and catch was 10,549 (thousands of fish), then the fishing effort index would be 1918 (10,549/5.5). This value plus the average fishing mortality during 1963 represent one point on the graph (point B). If a line can be fit statistically to all the points, a predictive relationship can be determined. In other words, if a fishing effort index can be obtained, an approximate value of the average fishing mortality can be estimated by referring to the graph. If in 1977 the autumn average catch per tow of 4 year fish and older was 13.5 and 1977 catch was 17,500 (thousands of fish), the fishing effort index would have been 1350 (17,500/13.5). From the graph, the corresponding average value of fishing mortality would be approximately 0.5 (point C).

The above procedure is only used when fishing effort cannot be accurately obtained from the fisheries themselves. When reliable commercial catch/effort data are available, catch can be divided by catch per unit effort to determine fishing effort. Attempts can then be made to establish a relationship between that effort and average fishing mortality.

7) From step 6 numbers of fish of each age in the stock at the beginning of 1978 is determined. To convert numbers of fish to total weight of the stock, the number of fish at each age is multiplied by the average weight of fish at the corresponding age and the results are added together. The procedure used is identical to the example shown in step 5.

8) The final step involves calculations of a group of options of catch and resultant stock size which managers, in this case the New England Council, can consider. By using procedures similar to those found in steps 6 and 7, the impacts of various amounts of catch on stock size at the beginning of next year can be presented. It then becomes the manager's responsibility to determine which catch/stock size option should be selected. For example, catches to maintain the same stock size or perhaps result in a 10% increase in stock size from 1978 to 1979 could be selected. Managers might decide to let the stock size decrease but not let it fall below some certain level, for example, the smallest stock size that has resulted in the production of strong year-classes in the past, and then set the allowable catch accordingly. Whatever the case may be, the choice to be made is outside the responsibility of the assessment scientists. One of their roles is to determine the impacts of potential management actions; that is, the effects of total stock removals, not to determine strategy.

The above example of a stock assessment is one of the more demanding types in terms of the amounts of information needed for its performance. Many years of commercial catches/landings records and annual samples of age and length composition are required. It is a sophisticated analysis which is neither simple to perform nor to understand by a layman. This is why we stated in our introduction that patient reading of this section is necessary.

The aforementioned type of assessment has been performed for the cod stock of Georges Bank/southern New England and a similar one has been done for haddock. Other types of assessments, such as the one used for yellowtail flounder, rely more heavily on the results of bottom trawl surveys. The type utilized depends on the kinds and amounts of reliable information which is available to the scientist.

REFERENCES

Anderson, E.D. 1978. An Explanation of Virtual Population Analysis. NEFC, Woods Hole, Mass., Lab. Ref. No. 78-09, 5 p.

Clark, S.H. and B.E. Brown. 1977. Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963-74, as determined from research vessel survey data. Fishery Bulletin. 75 (1):1-21.

Clark, S.H. and P.W. Wood. 1978. Sea sampling program of the Northeast Fisheries Center, Woods Hole, Mass. NEFC, Woods Hole, Mass., Lab. Ref. No. 78-31, 18 p.

Grosslein, M.D. 1969. Groundfish survey methods. NEFC, Woods Hole, Mass., Lab. Ref. No. 69-2, 34 p.

Grosslein, M.D. 1969. Groundfish survey program of BCF, Woods Hole, Commercial Fisheries Review. 31(8-9):22-35.

Grosslein, M.D. 1971. Some observations on accuracy of abundance indices derived from research vessel surveys. Int. Comm. Northwest, Atl. Fish. Redbook 1971 (III):249-266.

Gulland, J.A. 1966. Manual of sampling and statistical methods for fisheries biology: Part 1. Sampling methods. (FAO) Food Agric. Organ., United Nations.

Pennington, M.R. and M.D. Grosslein. 1978. Accuracy of abundance indices based on stratified random trawl surveys. Int. Comm. Northwest Atl. Fish. Res. Doc. 78/VI/77. 42 p.

Sissenwine, M.P., B.E. Brown, and J. Brennan-Hoskins. 1978. Brief history and state of the arts of fish production models and some applications to fisheries off the northeastern United States. To be published in "Report of the Climatology and Fisheries Workshop," March 1978, University of Rhode Island.

PERSONAL COMMUNICATIONS

Mr. Thomas Azarowitz, NMFS Fishery Biologist

Ms. Patricia Gerrior, NMFS Fishery Reporting Specialist

Mr. Ronnee L. Schultz, NMFS Fisheries Management Supervisor

ACKNOWLEDGEMENTS

Scientists of the Northeast Fisheries Center: Drs. Stephen H. Clark, Frederic M. Serchuk, Michael P. Sissenwine, Bradford E. Brown, Marvin D. Grosslein, and Emory D. Anderson offered many excellent and valuable comments, suggestions, and criticisms during reviews of two drafts of our manuscript. We greatly appreciate their input. We acknowledge the contributions of Messrs. Arnold B. Howe and H. Arnold Carr of the Massachusetts Division of Marine Fisheries; their reviews and suggestions were very beneficial. Dr. Guy Marchesseault, a New England Fishery Management Council biologist, also provided helpful advice.

GLOSSARY

Abundance Index Information obtained from samples or observations and used as a measure of the weight or number of fish which make up a stock.

Biomass Measure of the quantity, usually by weight in pounds or metric tons (2,205 pounds = 1 metric ton), of a stock at a given time.

Fishing Mortality Deaths in a fish stock caused by fishing.

Fishing Power The catch which a particular gear or vessel takes from a given density of fish during a certain time interval. For example, larger vessels (horsepower) have a greater ability to catch more fish, thus the greater their fishing power. Also, improvements in a vessel or gear, such as fish finders, Loran, etc., can increase fishing power.

Growth Overfishing The level of fishing which destroys small fish before their yield in weight due to growth is maximized.

Length Frequency An arrangement of recorded lengths which indicates the number of times each length or length interval occurs. For example, 10 measurements of lengths are taken in the following order: 10, 12, 12, 14, 12, 15, 15, 19, 12, and 10. A length frequency would be:

Length	Occurrence		Length Interval	Occurrence
10	2			
11	0		10-12	6
12	4		13-15	3
13	0	or	16-18	0
14	1		19-21	1
15	2			
16	0			
17	0			
18	0			
19	1			

Maximum Sustainable Yield (MSY) The largest long term average catch or yield that can be taken yearly from a stock under existing environmental conditions; often used as a management goal.

Natural Mortality Deaths in a fish stock caused by predation, pollution, senility, etc., but not fishing.

Optimum Yield (OY) The yield from a fishery which provides the greatest overall benefit to the nation with particular reference to food production and recreational opportunities; it is based on MSY as modified by economic, social or ecological factors.

Precision and Accuracy Precision is the closeness to each other of repeated measurements of the same quantity or object, while accuracy is closeness of a measured or computed value to its true value.

As an illustration, suppose regulations state that fishermen can only land 5,000 lbs. of cod per trip. A fisherman makes 10 trips with the intent to not exceed the 5,000 lbs. limit. Before landing each trip, he estimates that his total catch for each was approximately 5,000 lbs. However, after landing each trip, weigh-in's at a dealer showed that every catch was just about 5,500 lbs. The fisherman's estimates of his catch were, therefore, precise but not accurate.

Two fictional series of research vessel tows were made in a single stratum. The first series resulted in catches of 61, 55, 60, 64, 63 and 59 pounds. The second resulted in 10, 20, 45, 60, 110 and 115 pounds. Both resulted in mean catches per tow of 65 lbs. The first series of tows is a very precise estimate of abundance while the estimate of the second series is very imprecise. The range of values about the average in the first series (55-64) is much narrower than that of the second (19-115); therefore, confidence in the first average as an estimate of relative abundance is much greater than confidence in the second average. Nothing can be stated about the accuracy of either of the series of tows in providing estimates of true abundance. The degree of accuracy is affected by fish behavior, gear performance, and a possible mismatch between the timing and area of surveys in relation to fish movements and distribution.

Recruitment This term is used two ways. (1) Number of young produced from a given stock each year, or (2) addition of new fish to the catchable portion of a stock brought about by growth or migration of smaller fish; the catchable portion is influenced by the mesh size in use and fish distribution.

Recruitment Overfishing A decline in recruitment due to fishing pressure; that is, the parent or spawning stock is reduced to a level at which the potential number of young, which will eventually enter the fishery, is severely reduced. This is generally considered to be more serious than growth overfishing.

Relative Abundance An estimate of actual or absolute abundance; usually stated as some kind of index; for example, as bottom trawl survey stratified mean catch per tow.

Sample A proportion or a segment of a fish stock which is removed for study, and is assumed to be representative of the whole. The greater the effort, in terms of both numbers and magnitude of the samples, the greater the confidence that the information obtained is a true reflection of the status of a stock (level of abundance in terms of numbers or weight, age composition, etc.)

Standardization The procedure of maintaining methods and equipment as constant as possible. Without standardization one cannot determine whether measurements of yearly differences in relative abundance are caused by actual fluctuations in stock abundance or by differences in the measurement procedure used.

The lack of standardization is one reason why surveys using different commercial fishing vessels in different years do not produce comparable information. For example, if two vessels of different horsepower are used in separate years, the results can't be compared, unless vessel mensuration experiments are performed. This would involve a comparison of the two vessels' catches to determine the influence of their fishing power on the size of the catch, and a determination of a correction factor.

Stock A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery. A fish stock may be treated as a total or a spawning stock. Total stock refers to both juveniles and adults, either in numbers or by weight, while spawning stock refers to the numbers or weight of individuals which are old enough to reproduce.

Stratified Mean (Average) Catch Per Tow For separate species of fish, each average catch per tow — determined from a series of tows — in each geographic stratum of a region is multiplied by that area (square nautical miles) of the stratum in which the tows were made. All of the individual products are added together and the total is divided by the sum of the entire area of the region. The final result is the stratified mean catch per tow; this is used as an index of relative abundance. For example, a scientist wishes to calculate the stratified mean catch per tow of cod in a region (perhaps Georges Bank) that measures 100 square nautical miles. The region has been divided into 5 strata on the basis of depth. In each strata, 5 tows are made and the average catch of cod calculated.

Stratum	# Tows	Sq. Nautical Miles	Average Catch Per Tow (lbs.)	
1	5	20	30	20 x 30 = 600
2	5	40	40	40 x 40 = 1600
3	5	15	10	15 x 10 = 150
4	5	10	5	10 x 5 = 50
5	5	15	15	15 x 15 = 225
		100 (total area of the region)		2625 total

Stratified Mean Catch Per Tow = 26.25 pounds (2625 ÷ 100)

as opposed to a simple mean or average of
(30 + 40 + 10 + 5 + 15) ÷ 5 = 20 pounds

Yield Per Recruit The expected yield in weight from an individual fish over its life in the fishery. The yield is influenced by its age at entry to the fishable stock and by mortality rates. The maximum yield per recruit which can be obtained is often used as a management goal.

Year-Class Fish of a given species spawned or hatched in a given year; a three-year old fish caught in 1978 would be a member of the 1975 year-class.

A

B

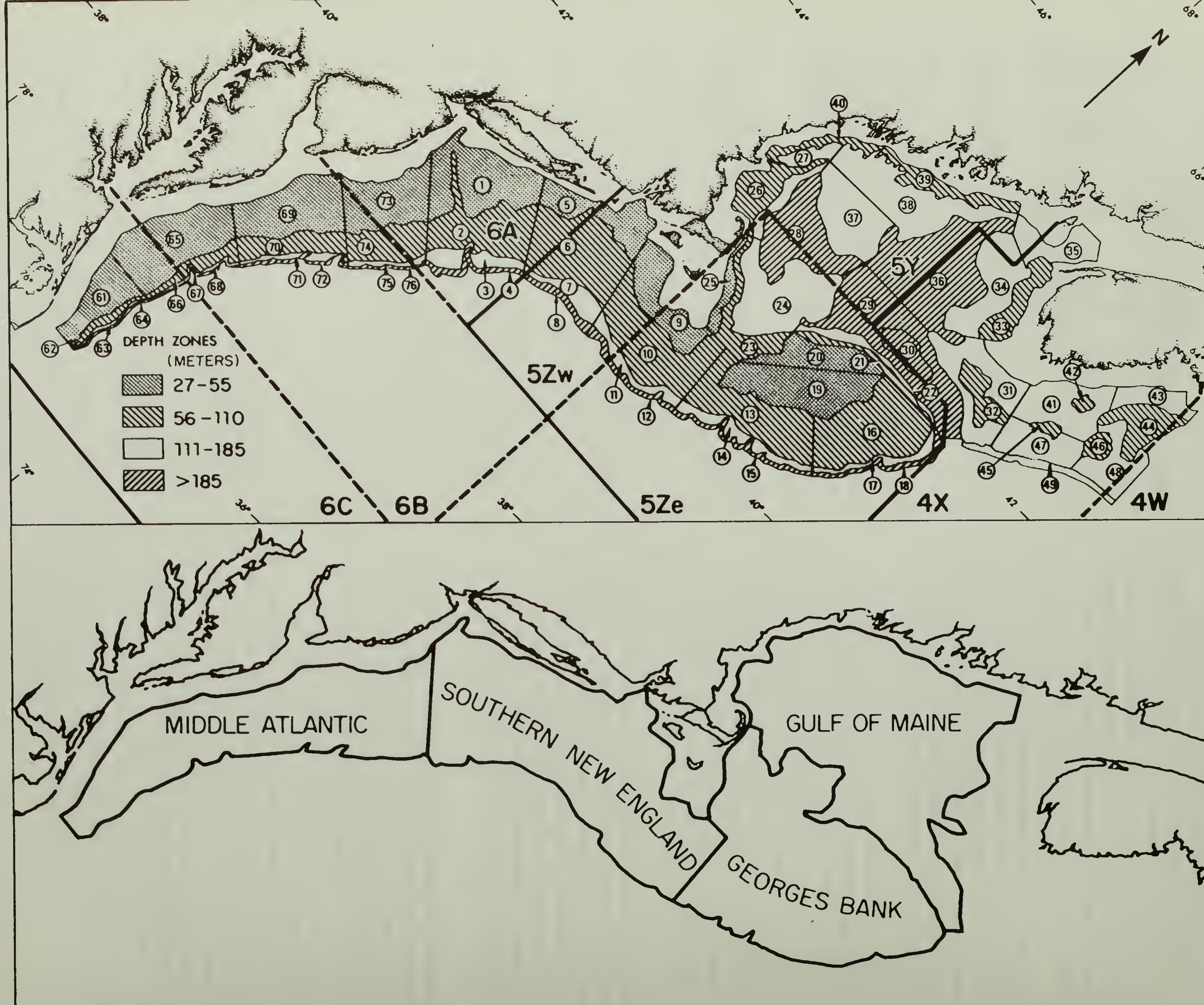


Fig. 1 Northwest Atlantic area from Nova Scotia to Cape Hatteras, a) delineated into strata by depth, with ICNAF division boundaries superimposed and b) delineated into major units for analytical purposes. (Source — Clark, S.H., and Brown, B.E. 1977.)

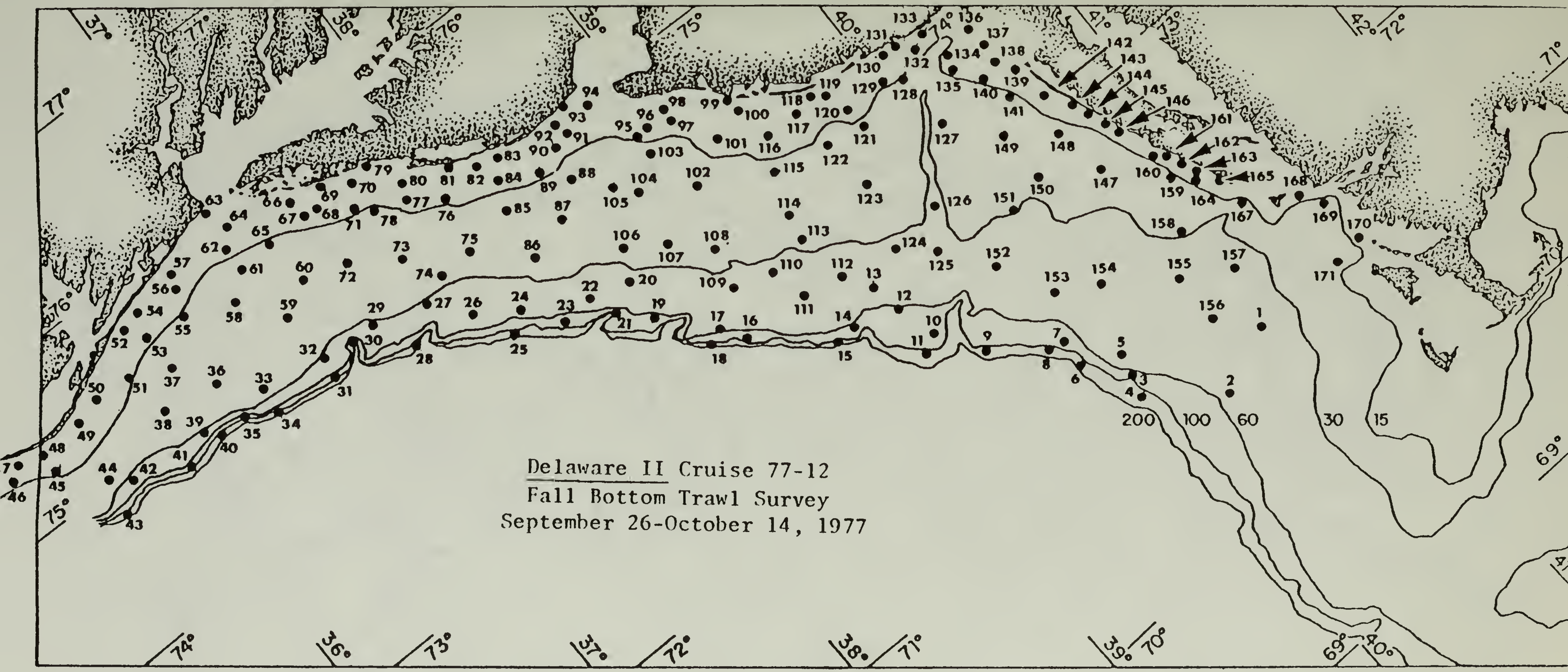


Fig. 2 The above stations, numbered 1-171 and covering southern New England and the mid-Atlantic shelf, were completed during the Delaware II southern part of the Fall Bottom Trawl Survey.

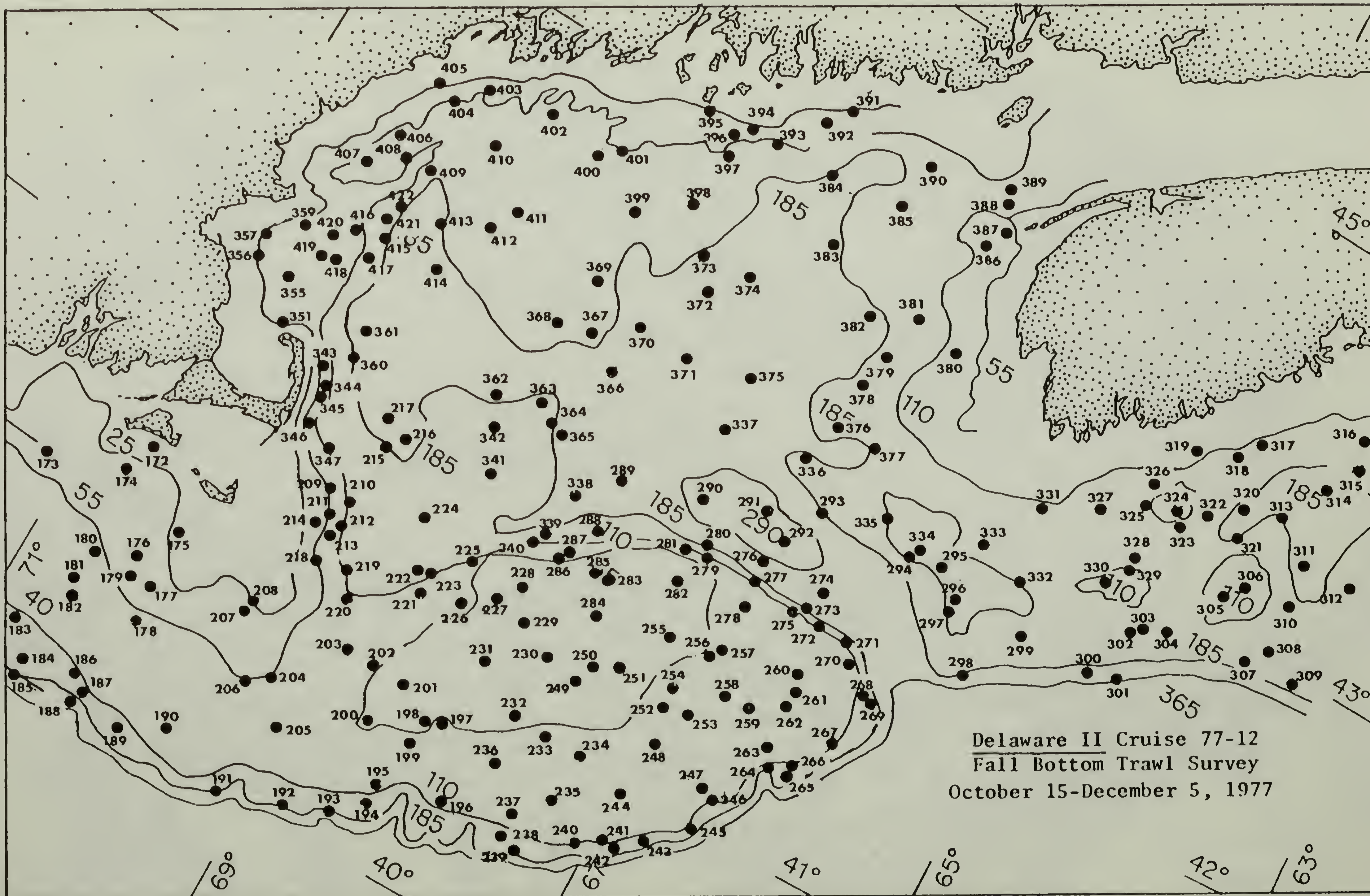


Fig. 2 The above stations, numbered 172-422 and covering Georges Bank and west to 71°, the Gulf of Maine and the Scotian Shelf, were completed during the Delaware II northern part of the 1977 Fall Bottom Trawl Survey.

Fig. 3 Fisheries Statistical Areas and Northeast Regional Branch of Statistics Office Locations